# Quantum precision measurement of two-dimensional forces with $10^{-28}$-Newton stability

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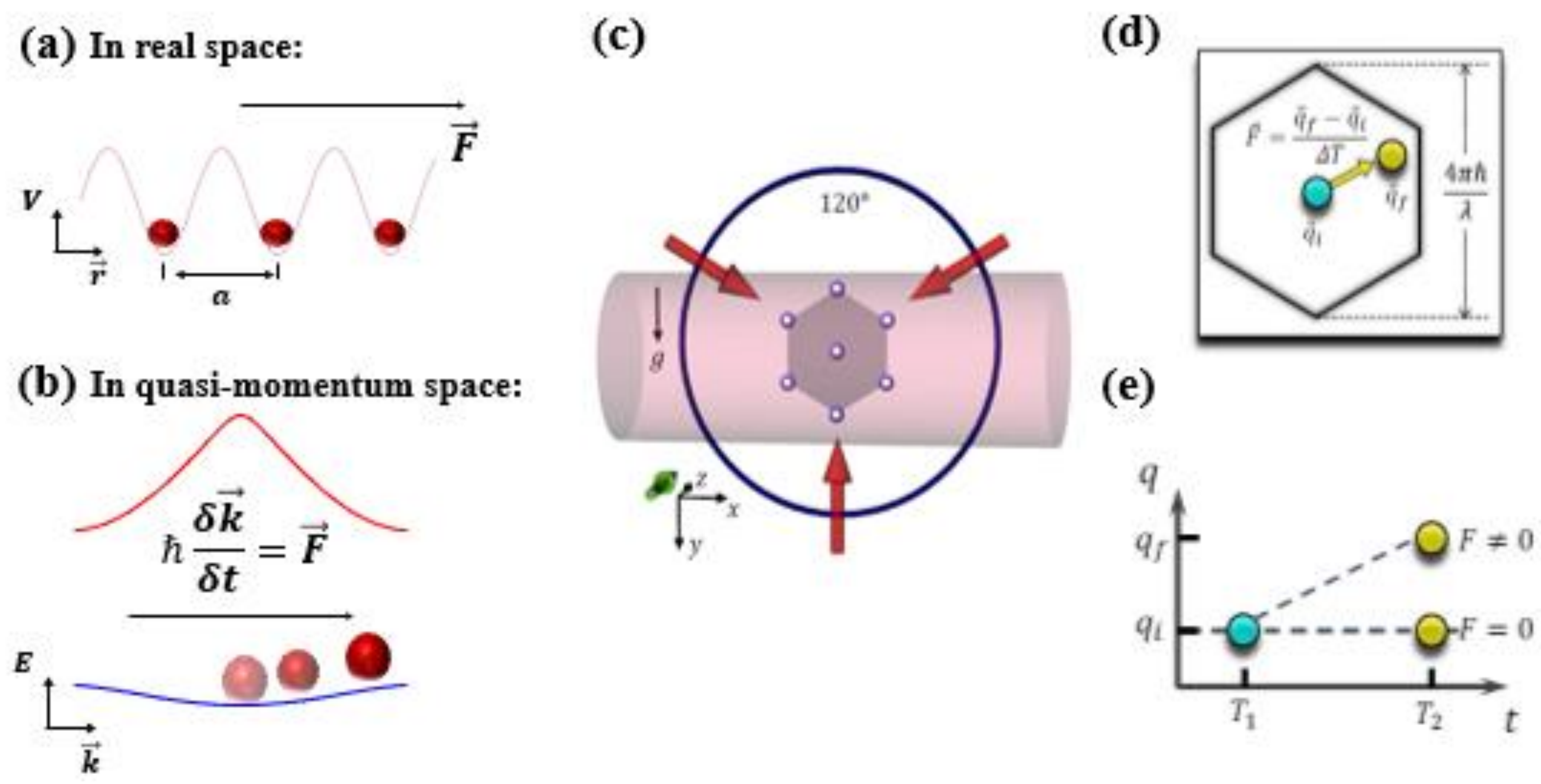
## Bloch Oscillations of BECs in optical lattice




- F. Bloch has proposed the dynamics of electrons under constant electric field in periodic field in 1928: when a particle experiences the force in a periodic potential, it performs periodic oscillations.
- For BECs in optical lattice under an external force, the quasi-momentum increases linearly.

## Change of quasi-momentum in Bloch Oscillations

- Tight-binding model for 1D lattice

$$E(k) = -W\cos(ka)/2,$$

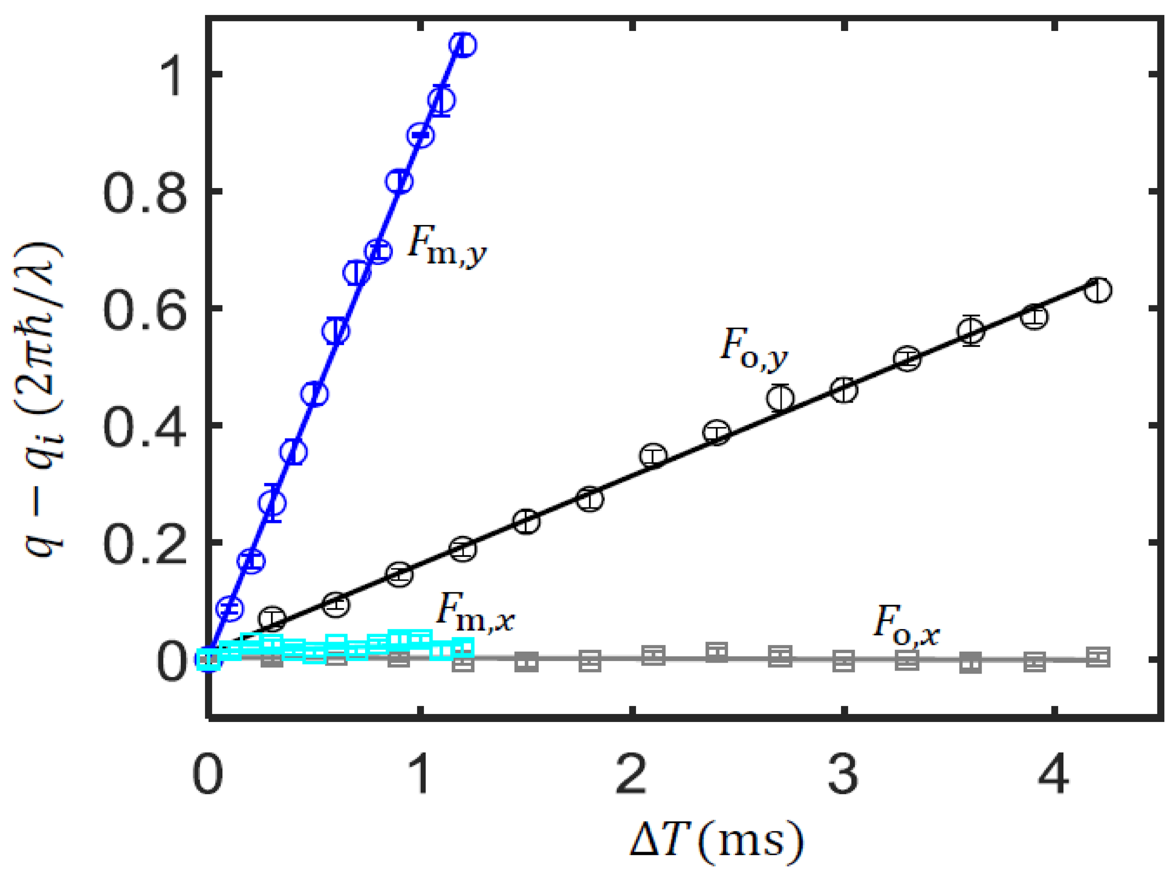
where $W$ is band width, $a$ is the lattice constant, $k$ is wave vector.

- The group velocity is

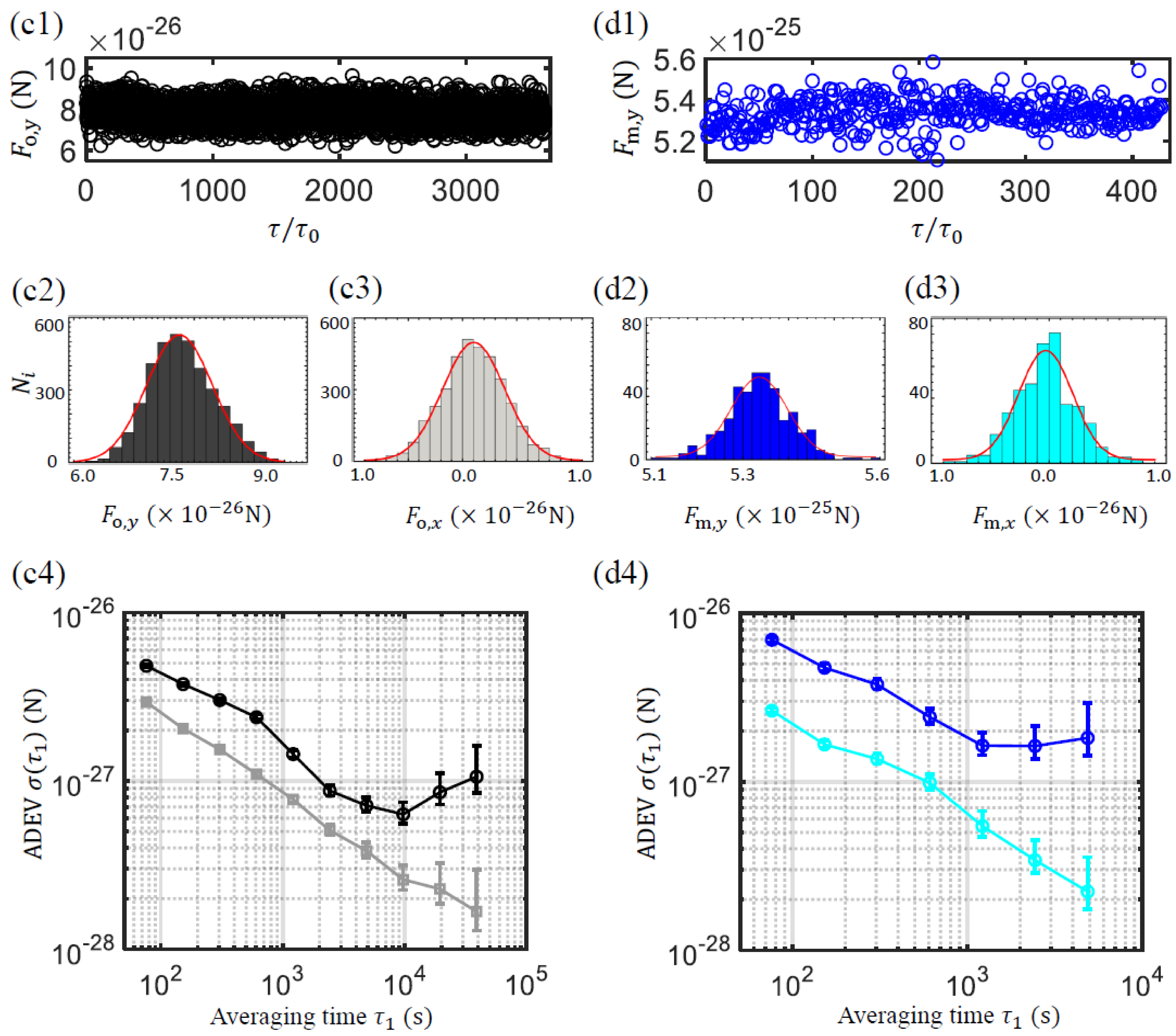
$$v(k) = \frac{1}{\hbar}\frac{dE(k)}{dk} = \frac{Wa}{2\hbar}\sin(ka).$$

- The quasi-momentum of atoms under external force $\vec{F}$:

$$\vec{k} = \frac{\vec{F}t}{\hbar}\mathrm{mod}\left(\frac{2\pi}{a}\right).$$




## Vectorial force sensor based on Blcoh oscillations of BECs in triangular optical lattice




- A sensor for vectorial force based on quantum wave dynamics using light crystal BEC system:
  - Sensitivity of $2.30(8)\times10^{-26}$ N/$\sqrt{\mathrm{Hz}}$.
  - Long-term stabilities on the order of $10^{-28}$ N.
- Quantum force sensing based on atoms is of great significance in quantum scanning probe microscopy, Casimir force measurement and other fields.

Guo et. al., Science Bulletin, 2022, 67(22): 2291–2297